

The beam already knows what emittance it should deliver, we just have to measure it !

Content:

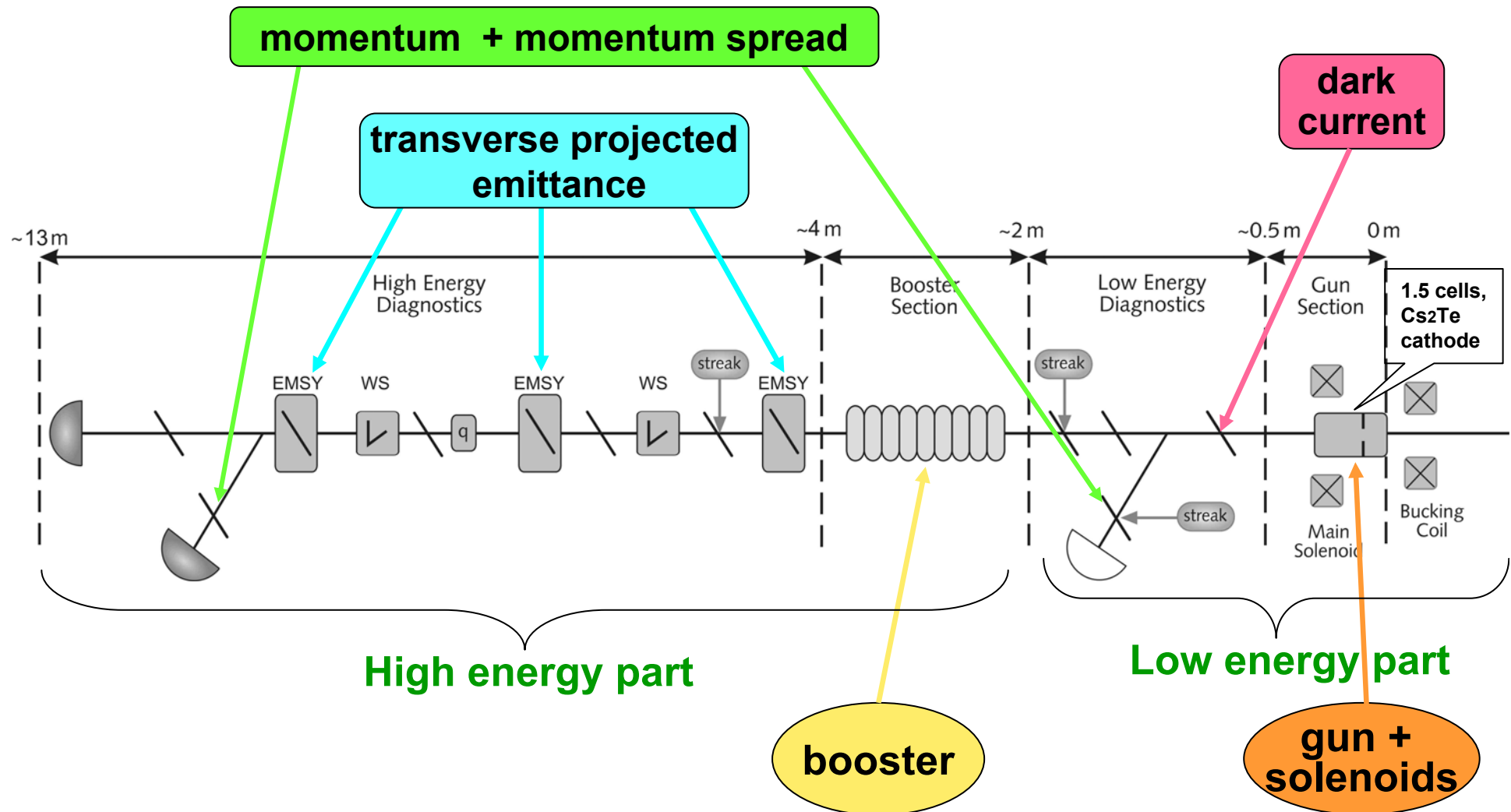
- measurement setup
- cathode laser
- different guns
- longitudinal phase space
- transverse projected emittance
- cathode studies
- future upgrades of the facility

Colleagues actively participating in measurements / new design:

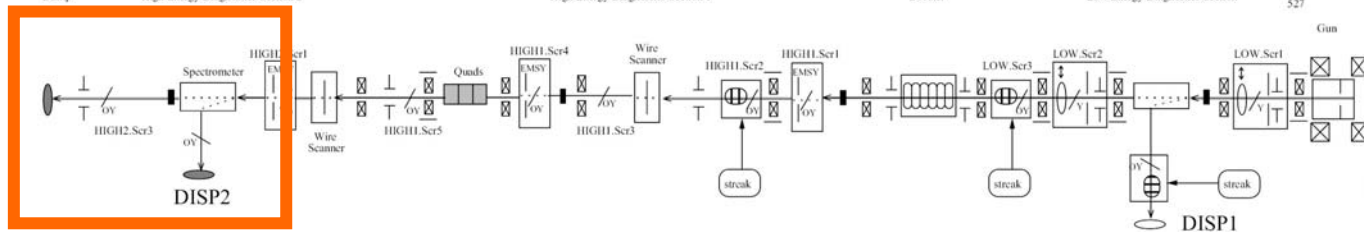
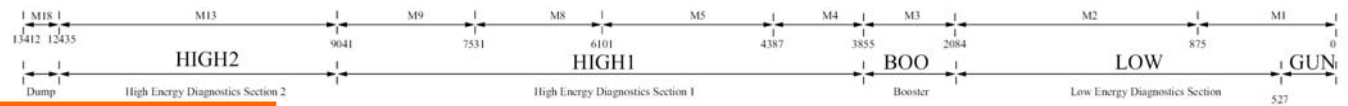
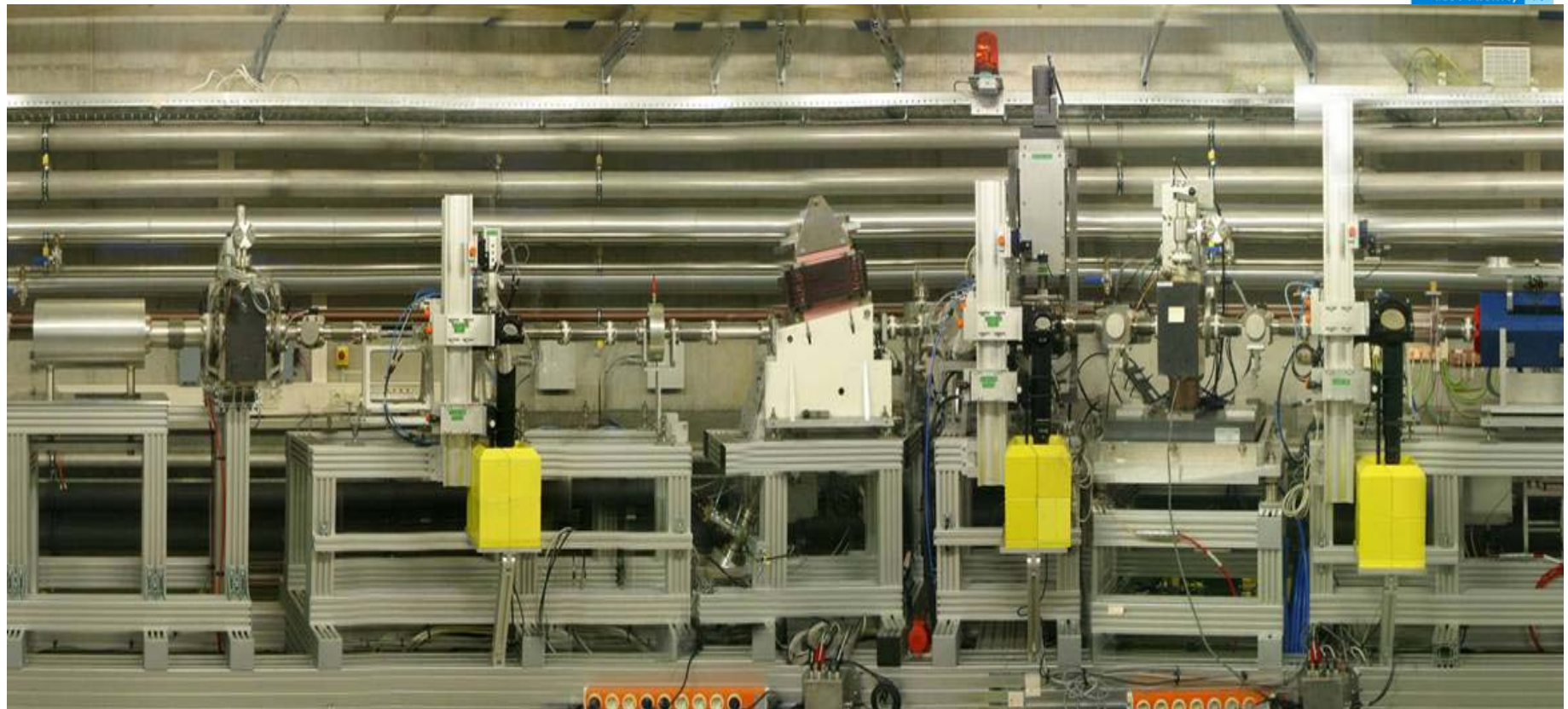
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- **Acknowledgements:** R. Brinkmann, U. Gensch, E. Jaeschke, L. Kravchuk, V. Nikoghosyan, C. Pagani, L. Palumbo, J. Rossbach, W. Sandner, S. Smith, T. Weiland, G. Wormser

Present layout of PITZ

This setup was used for the measurements to be presented:

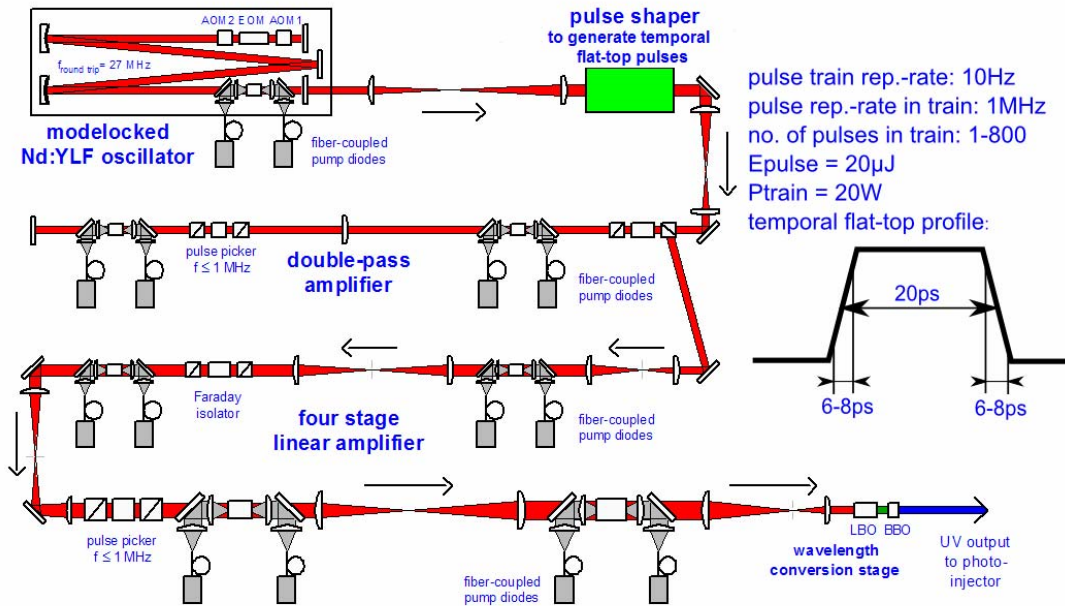


Present layout of PITZ

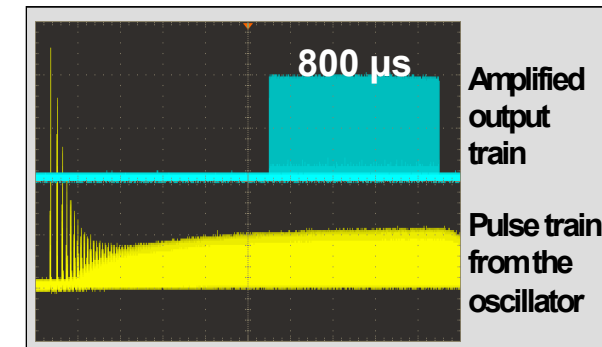


Version 6.2.07

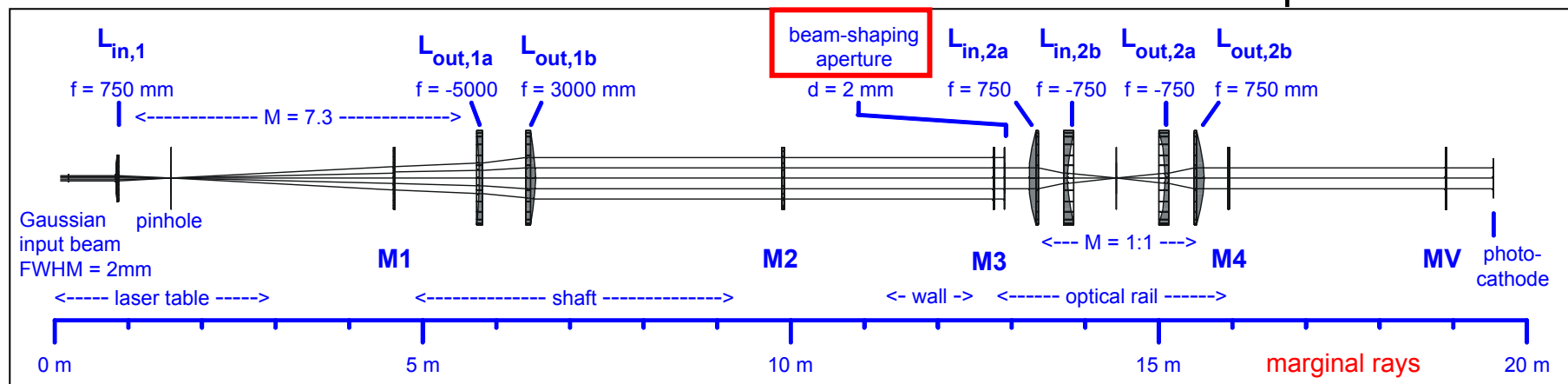
Photo cathode laser



Schematics of the diode-pumped Nd:YLF photo cathode laser system

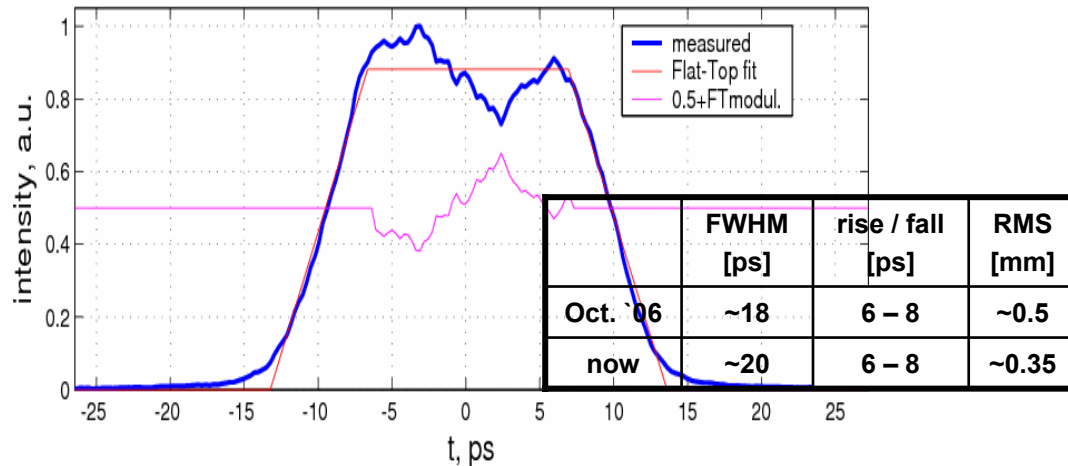


Beamline to photo cathode

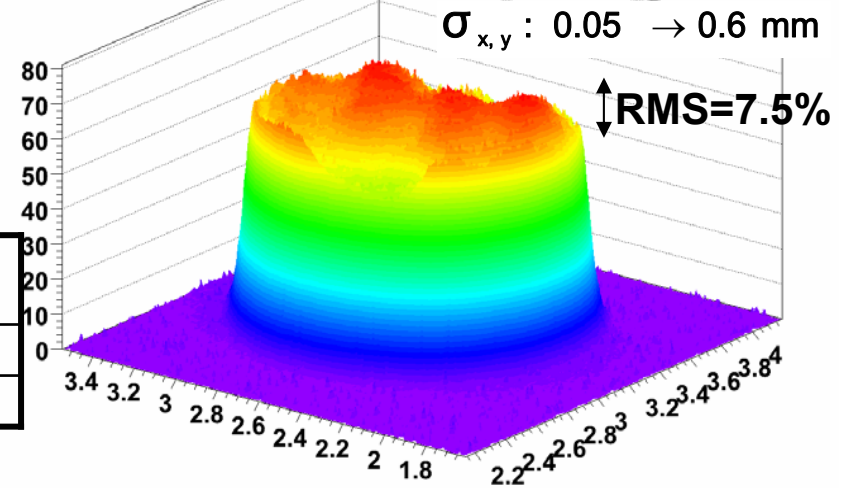


• longitudinal profile:

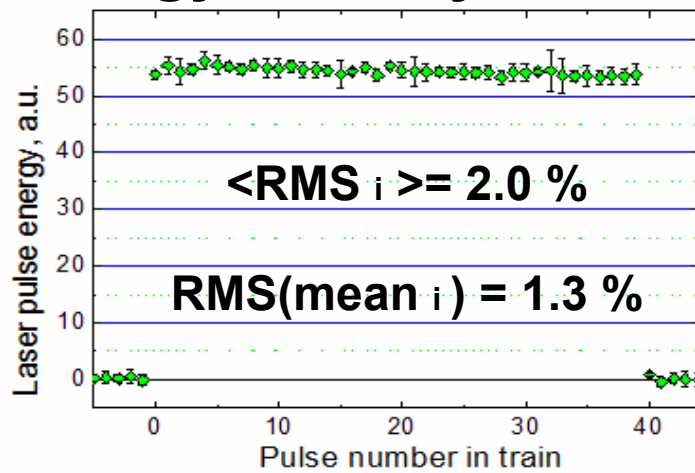
FWHM=20.22ps; rt1=6.58ps; rt2=6.67ps; FTmod=6.52%



• transverse profile:

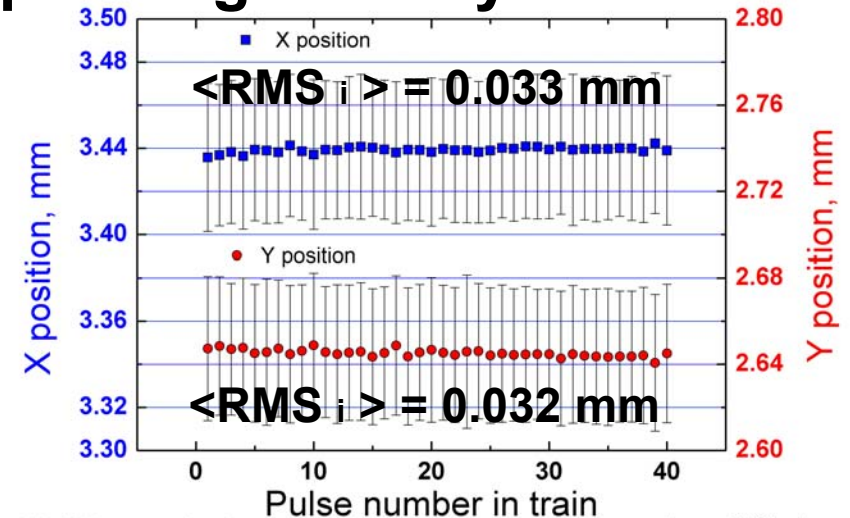


• energy stability:



50 trains

• pointing stability:



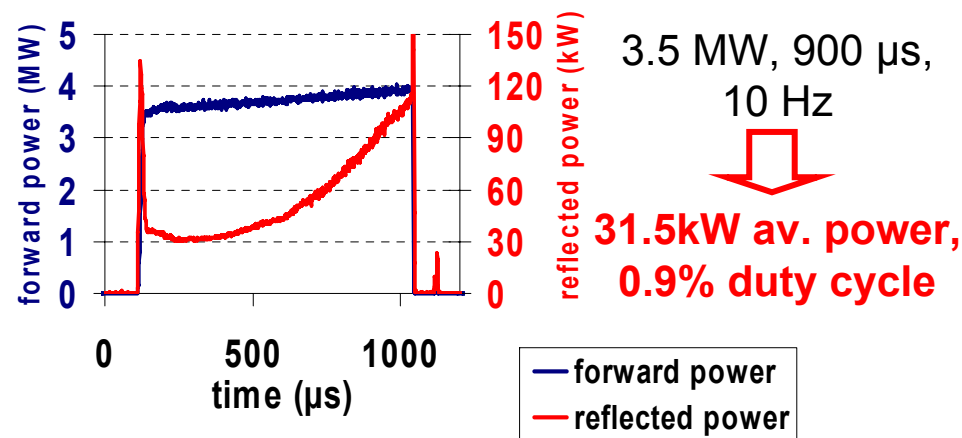
Hybrid Detector: Quadrant diode + CCD matrix

averaged over 200 trains

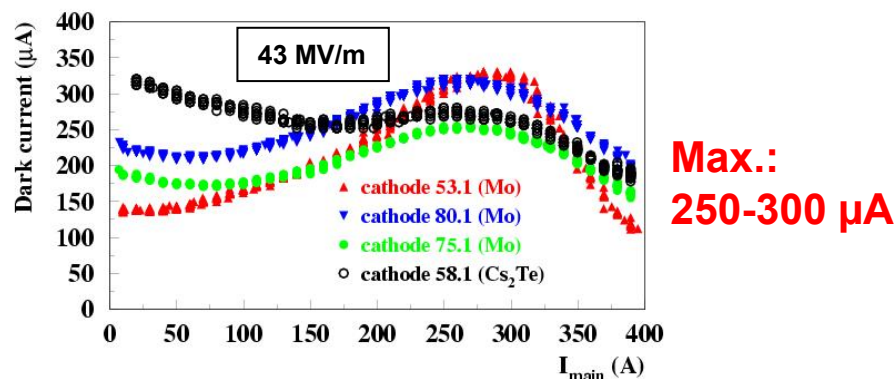
- Gun 3.1** –

characterized @ $\sim 40\text{MV/m}$ in Oct. '06
 → spare gun for FLASH

- Peak and average power:**



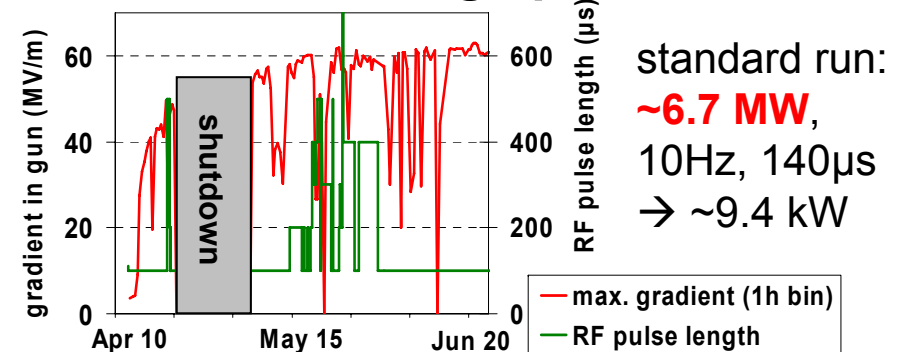
- Dark current:**



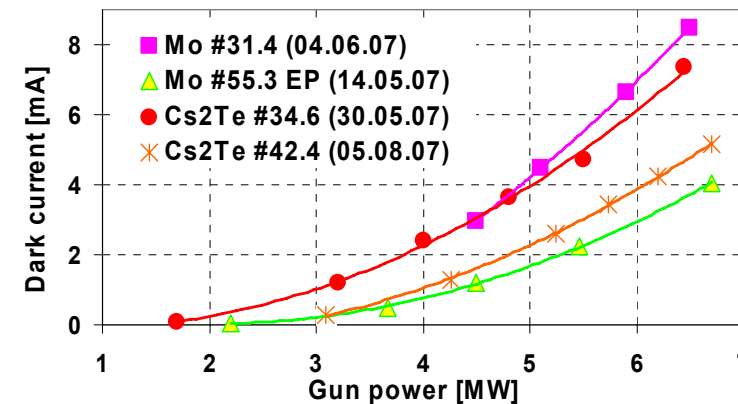
- Gun 3.2** –

characterized @ $\sim 60\text{MV/m}$ in summer '07
 → first experience with long RF at 60 MV/m

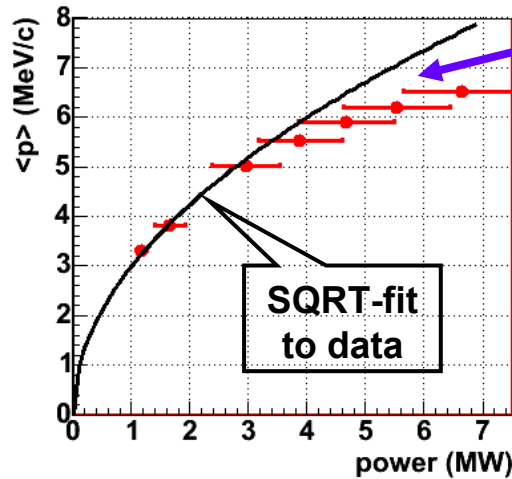
- Peak and average power:**



- Dark Current:**



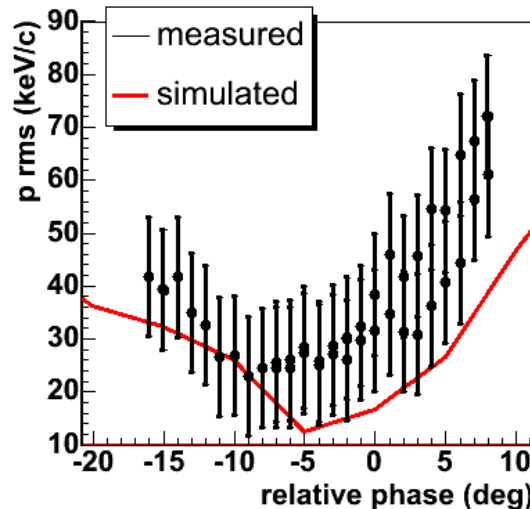
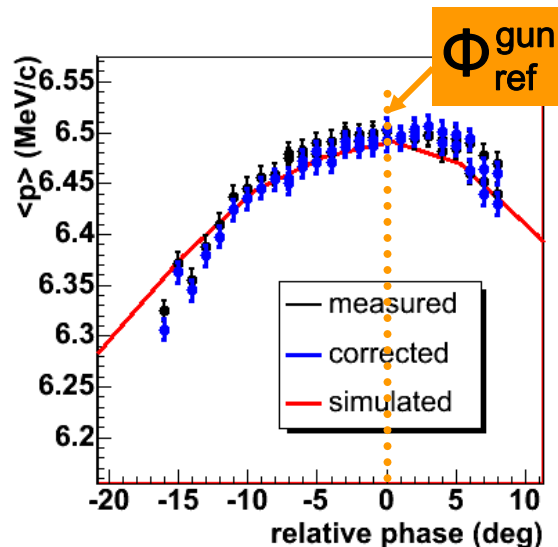
→ very high ! → possible reason: cavity fabrication error in cathode region



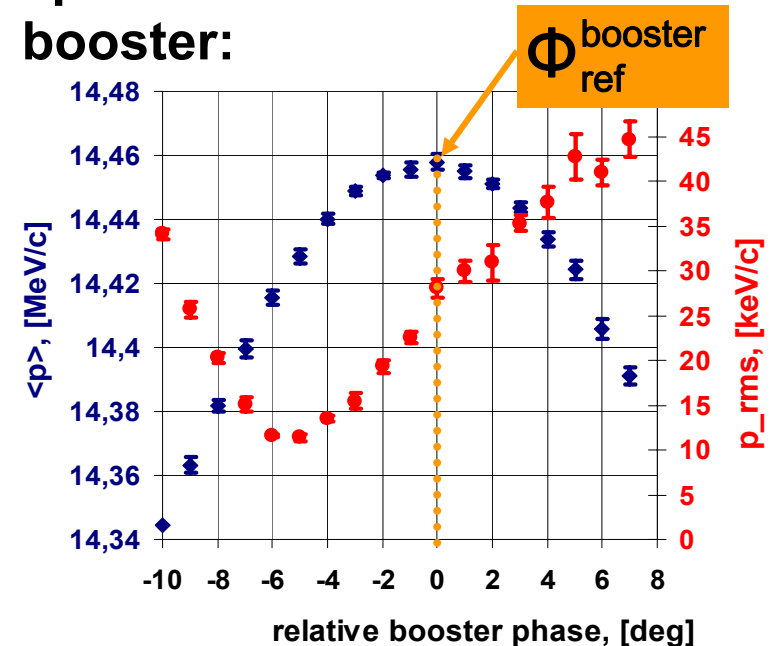
Problem with maximum momentum:

- measured momentum lower than expected from RF power readings
- possible reason:
→ power measurements

Momentum and momentum spread downstream of the gun:



Momentum and momentum spread downstream of the booster:



Projected Emittance Measurements: → Slit Scan Technique

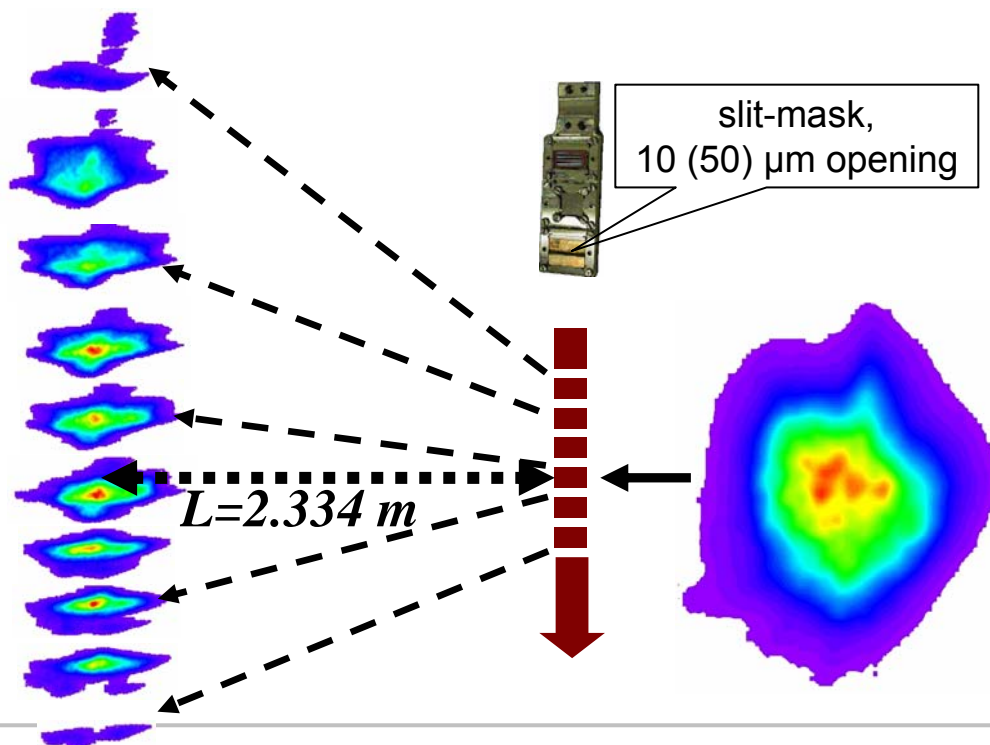
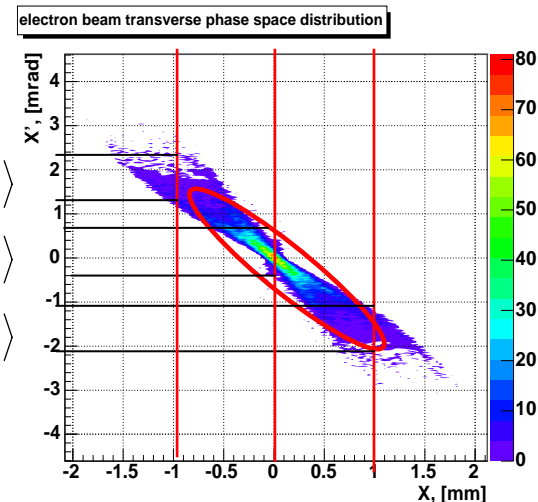
$$\mathcal{E}_{x,n} = \beta\gamma \cdot X_{rms} \cdot X'_{rms}$$

X_{rms} - RMS size of full beam at EMSY station (e.g. $z = 4.3\text{m}$)

$$X'_{rms} = \frac{1}{L} \sqrt{\frac{\sum_{i=1}^n w_i \cdot (X_{rms}^{beamlet})_i^2}{\sum_{i=1}^n w_i}} \quad \text{- uncorrelated local divergence}$$

$X_{rms}^{beamlet}$ - RMS size of the beamlet image

L - distance from slit location to screen for beamlets



- **Current standard procedure:**
 - take 11 equidistant beamlets over the full beam size
 - use 10 μm slit opening
 - ultimate resolution (current setup):
→ 36 μm x 15.4 μrad
 - use camera with 12 bit signal depth for beamlet measurements

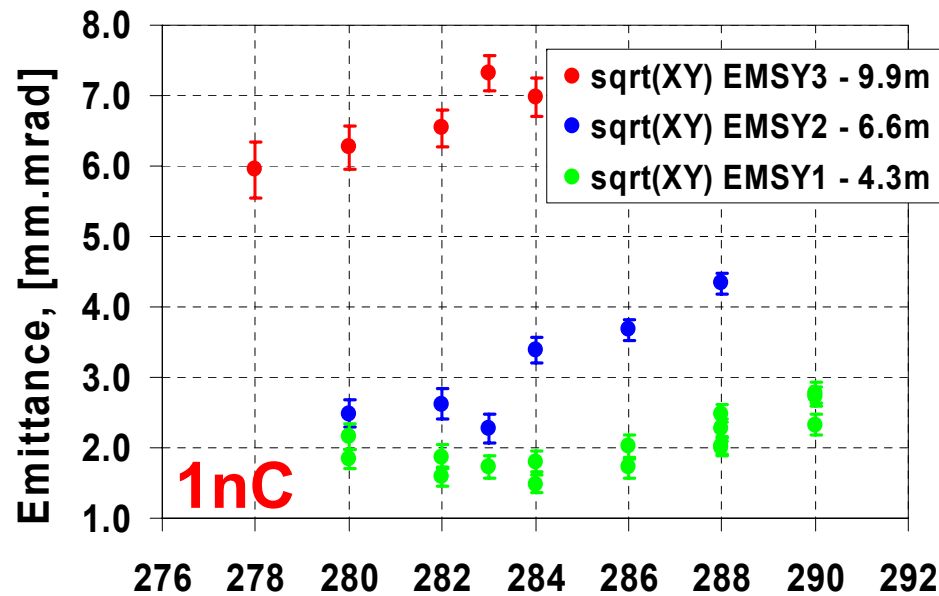
Gun gradient: $\sim 43\text{MV/m}$

Gun phase: $\Phi^{\text{gun}} = \Phi_{\text{ref}}^{\text{gun}} - 2 \text{ deg}$

Momentum from gun: $\sim 5.0 \text{ MeV/c}$

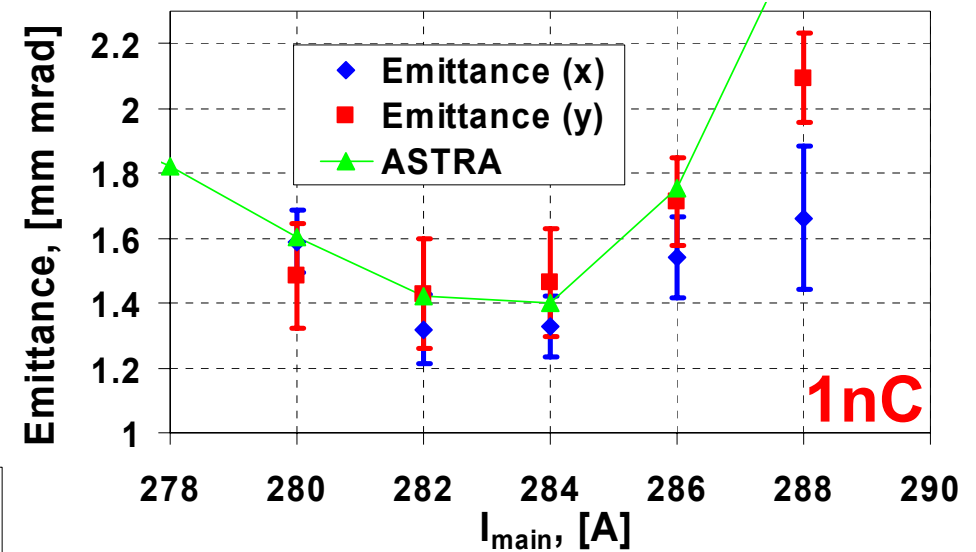
Booster phase: $\Phi^{\text{booster}} = \Phi_{\text{ref}}^{\text{booster}} - 5 \text{ deg}$

Total beam momentum: 12.8 MeV/c



$\Phi^{\text{gun}} = \Phi_{\text{ref}}^{\text{gun}} - 2 \text{ deg}$

$\Phi^{\text{booster}} = \Phi_{\text{ref}}^{\text{booster}} - 15 \text{ deg}$



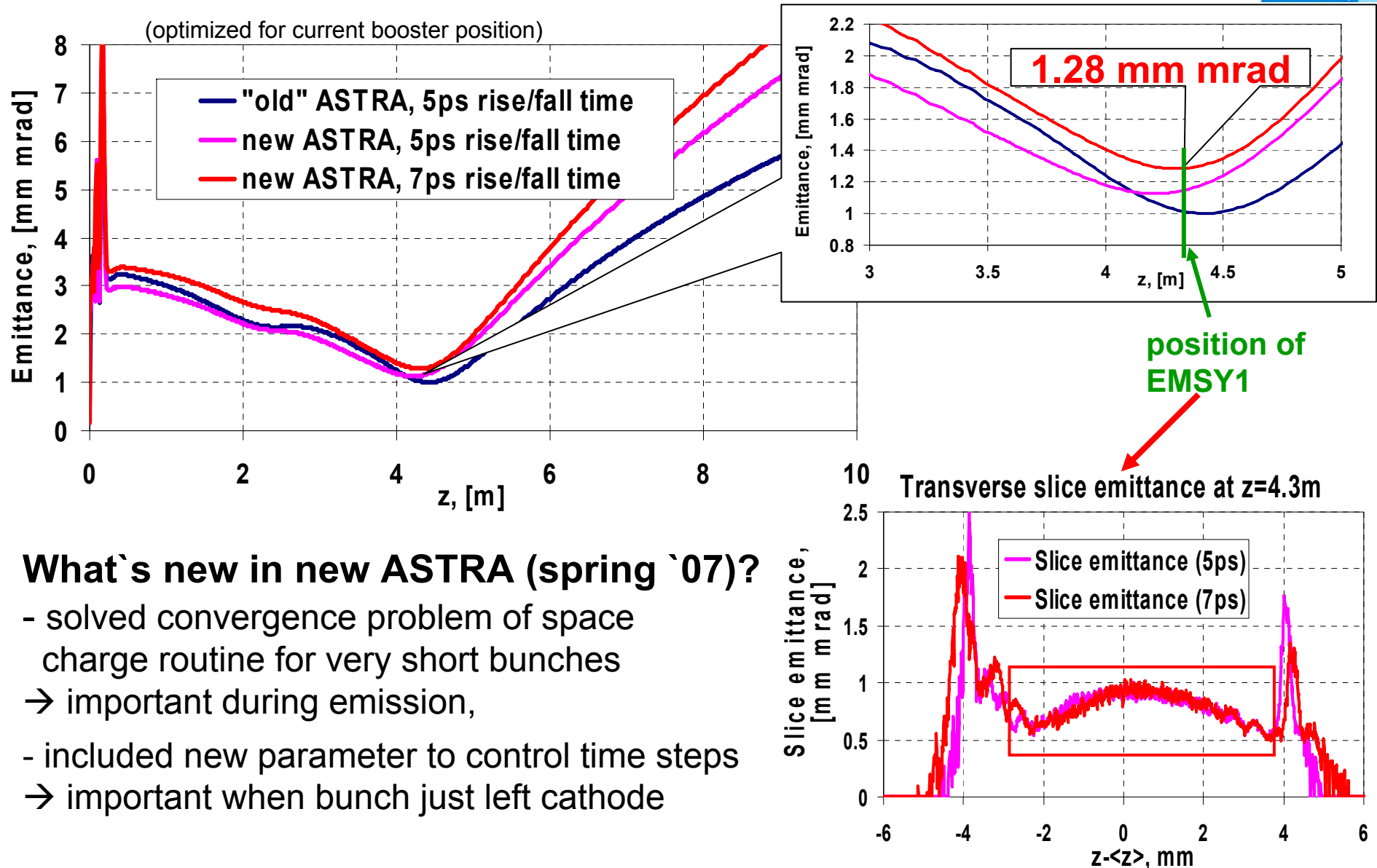
→ for 43 MV/m we obtained

$$\epsilon_{x,n} = 1.32 \pm 0.11 \text{ mm mrad}$$

$$\epsilon_{y,n} = 1.43 \pm 0.17 \text{ mm mrad}$$

@1nC

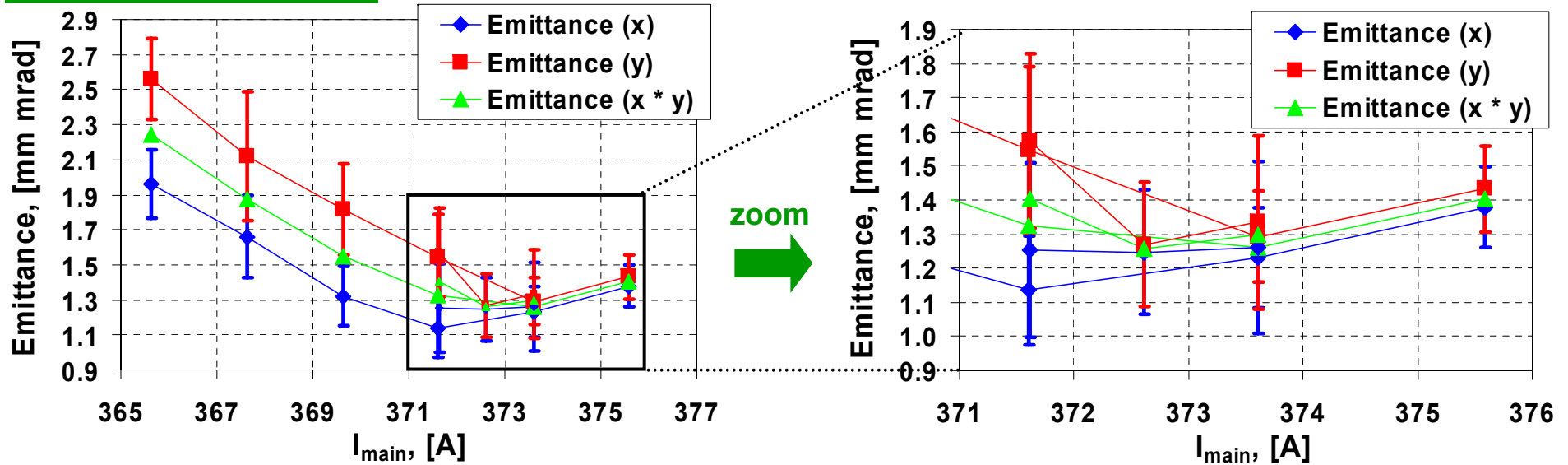
→ emittance strongly increases with distance from booster



What's new in new ASTRA (spring '07)?

- solved convergence problem of space charge routine for very short bunches
→ important during emission,
- included new parameter to control time steps
→ important when bunch just left cathode

preliminary analysis



Cathode: # 90.1

Gun gradient: ~ 60 MV/m

Gun phase: $\phi^{gun} = \phi_{ref}^{gun}$

Momentum from gun: ~ 6.44 MeV/c

Booster phase: $\phi^{booster} = \phi_{ref}^{booster}$

Total beam momentum: 14.5 MeV/c

→ for ~60 MV/m we obtained

$\epsilon_{x, n}$	= 1.25	± 0.19	mm	mrad
$\epsilon_{y, n}$	= 1.27	± 0.18	mm	mrad

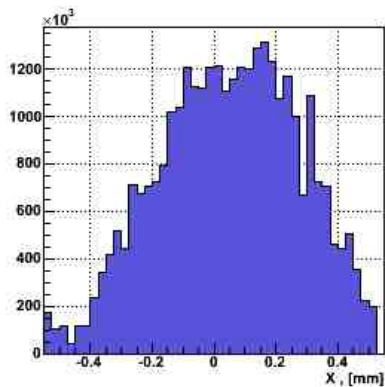
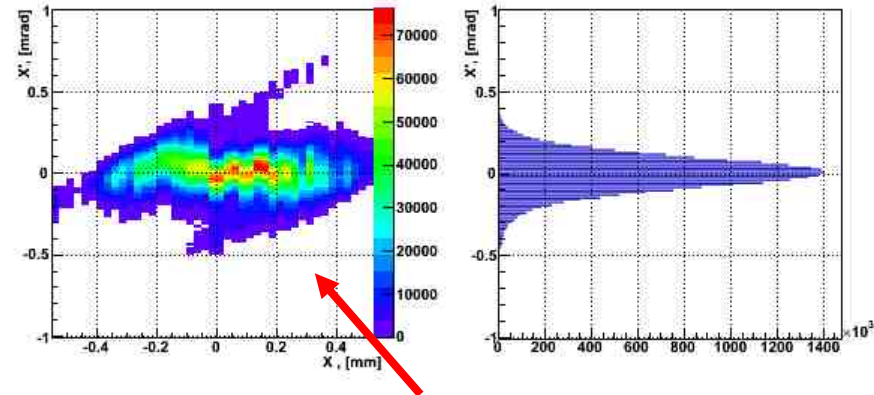
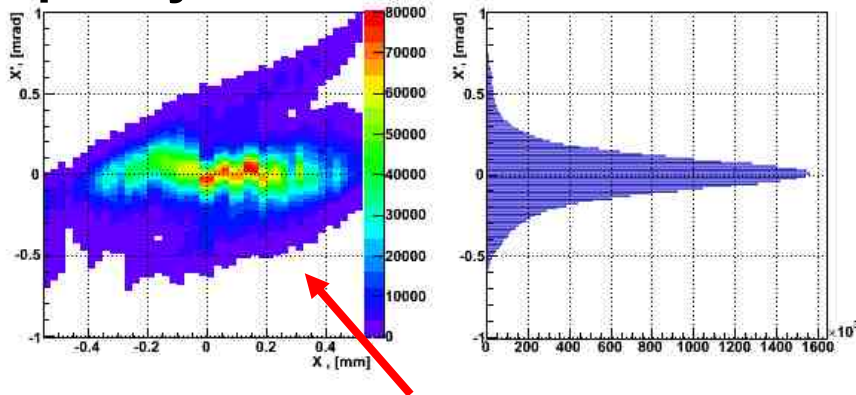
@1nC

for 100 % RMS emittance !

→ good agreement with prediction from ASTRA

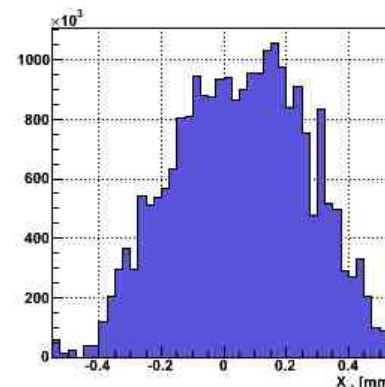
preliminary analysis

x-x'-phase space distribution for the best emittance measurement, purely reconstructed from subsequent beamlet measurements:



Emittance calculated purely from beamlet measurements, 100 % of data

→ $\epsilon_n = 1.1$ mm mrad



Cut at 5% of max. amplitude (i.e. 6.5% of “charge”) [reasons: noise, gain, sensitivity, bit depth, ...]

→ $\epsilon_n = 0.69$ mm mrad

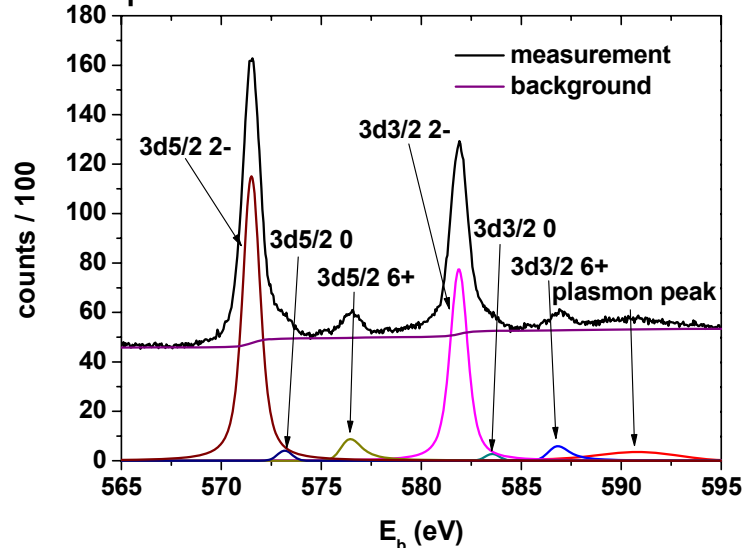
Reminder: This $\epsilon_n \neq 1.25$ mm mrad because the separately measured beam size at the slit position is NOT taken into account here.

→ projected emittance is reduced by 37 % !!

ASTRA: - 5% in particles → -38% in proj. emittance

For 95% RMS → $\epsilon_{x,y,n} \approx 0.8$ mm mrad

Te 3d spectrum for **fresh** cathode #90.1



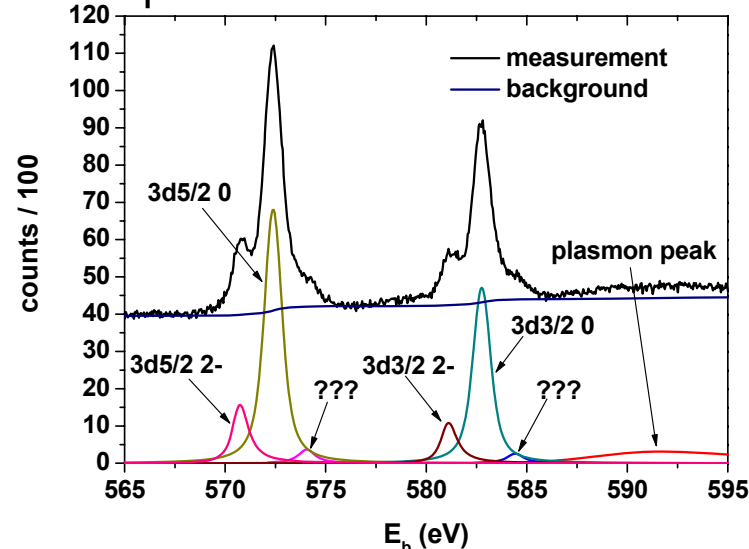
fresh cathode:

- dominant peaks for both spin-orbit couplings corresponding to Te^{-2} (Cs_2Te)
- small amounts of Te^0

used cathode:

- dominant peaks for both spin-orbit couplings corresponding to Te^0 (metallic tellurium)
- only small amounts of Te^{-2} (Cs_2Te)

Te 3d spectrum for **used** cathode #92.1



Confirmation from survey scan:

Te^{+6} visible (TeO_3) on fresh cathodes
but no oxidized states on used cathodes

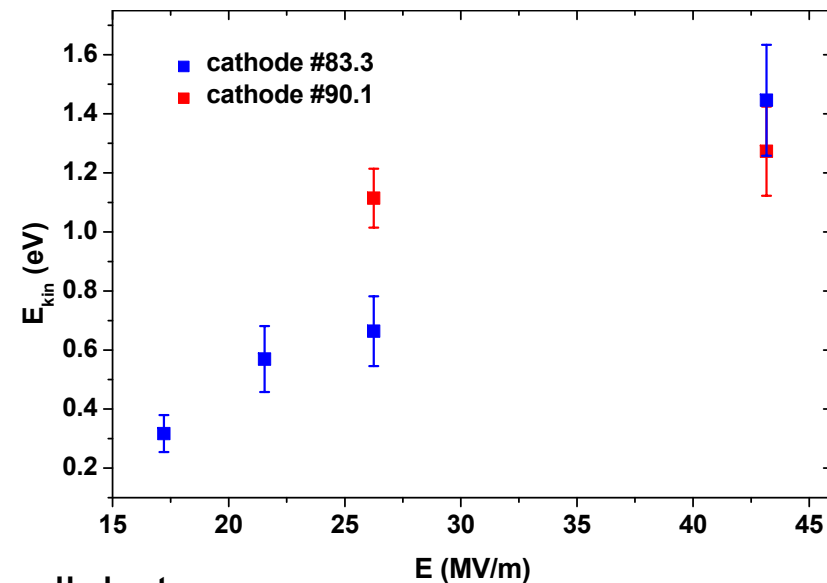
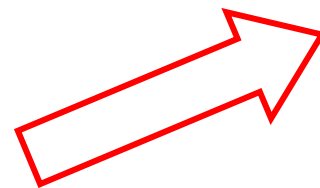
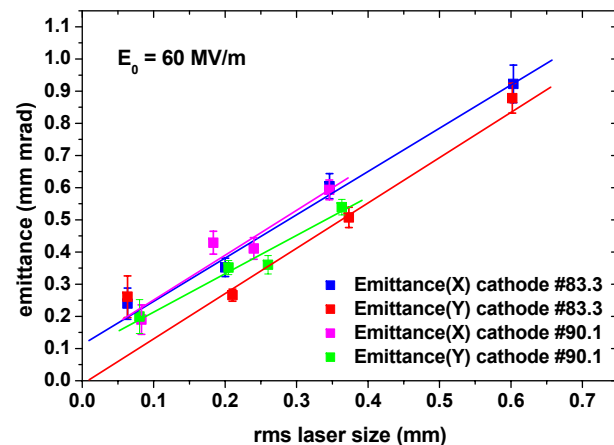
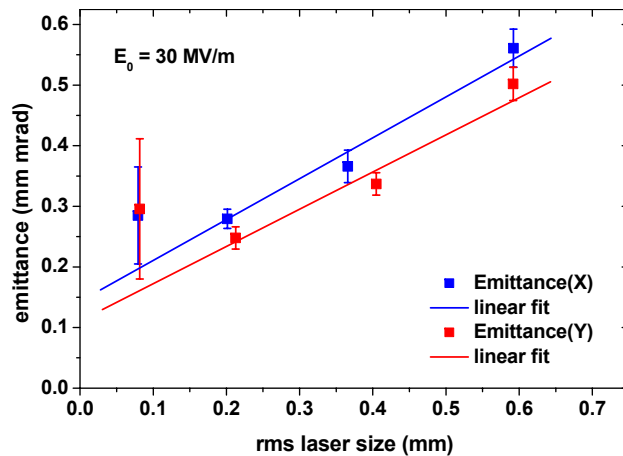
- **QE degradation during operation most probable related to change in chemical composition**
- **transition from Cs_2Te to metallic Te**

$$\mathcal{E}_{th} = \sigma_{cathode} \sqrt{\frac{2E_{kin}}{3m_0c^2}}$$

$$\mathcal{E}_{meas} \approx \sqrt{\mathcal{E}_{th}^2 + \mathcal{E}_{SC}^2 + \mathcal{E}_{RF}^2}$$

measure \mathcal{E}_{th} vs. $\sigma_{cathode}$ for low charge ($\leq 6\text{pC}$) and short pulse length ($\sigma_{laser} \approx 3\text{-}4\text{ps}$) $\rightarrow E_{kin}$

Expected E_{kin} for Cs₂Te cathode and 262 nm laser: **0.55 eV**
(this does not consider: field on cathode, change of cathode properties during operation)



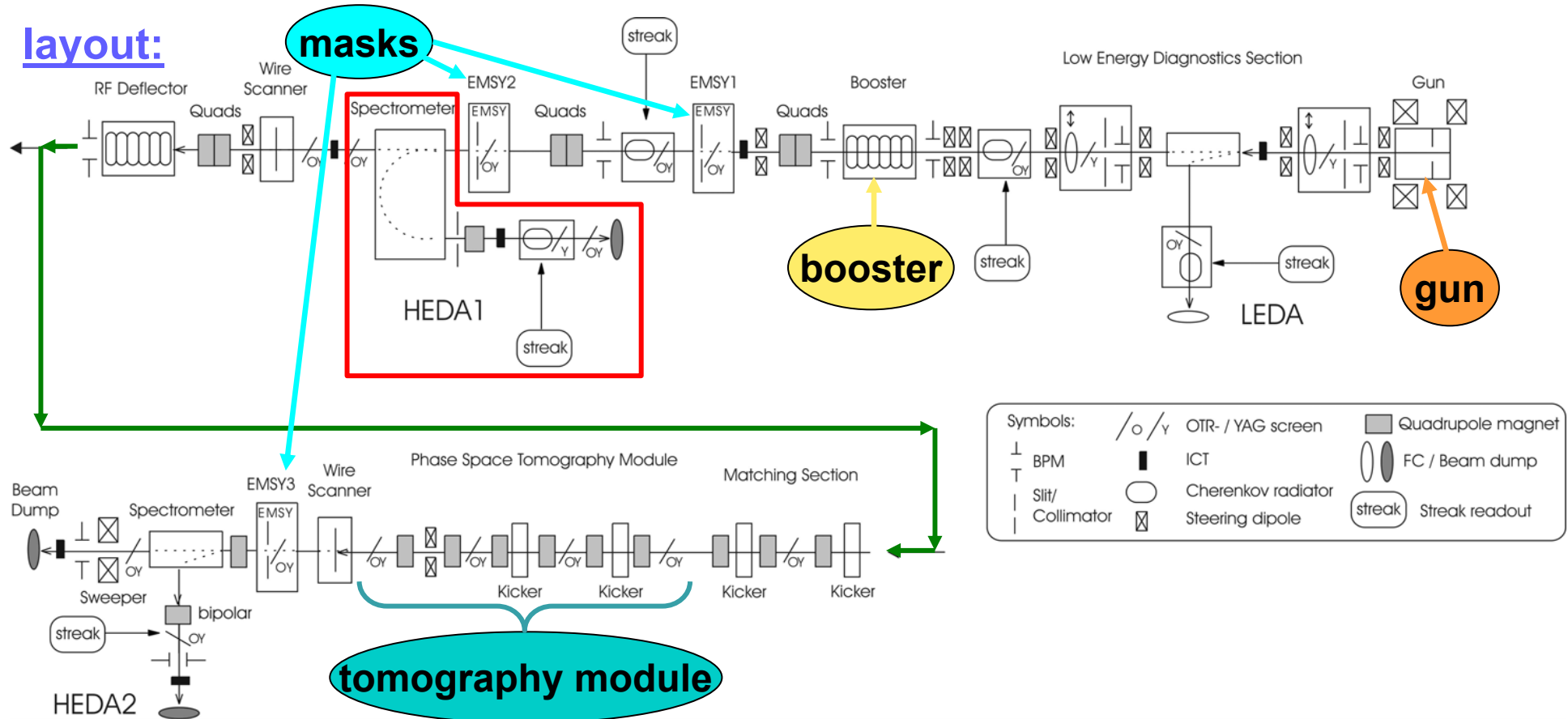
Error bars not small, but

- there is **increasing E_{kin}** with gradient at cathode !
- different **cathodes** can behave differently !
- **$E_{kin} \approx 1.4 \text{ eV} @ E_0 = 60 \text{ MV/m}$** \rightarrow 2 x larger than model
 \rightarrow for $\sigma_{cathode} = 0.35 \text{ mm}$ $\rightarrow \mathcal{E}_{th} = 0.47 \text{ mm mrad}$ ($\sim 50\%$)

Future upgrades at PITZ

- this autumn:**
- install improved **laser** system (20 ps FWHM, **rise/fall time ≤ 2 ps**)
 - install improved dispersive arm downstream of booster (HEDA1)
 \rightarrow **slice emittance measurements**
 - condition **new gun** cavity to 60 MV/m
- 2008:**
- install new CDS **booster** and **tomography section**
 - start experimental optimization for **European XFEL baseline parameters**

layout:



- **Dark current from cavity 3.2:** although dark current was reducing during conditioning/operation → **still very high at 60 MV/m**. We assume that one main reason is a **fabrication error** which did not happen again at later cavities. **New cavity 4.2** was **cleaned with CO₂** and **conditioning** will start on a separate test stand in **November 2007**.
- **Life time of photo cathodes:** only up to **~1 week** in last run period. Reason not clear. Might be related to high **level of dark current**, may be in addition related to **Flour** impurities in the vacuum system.
- **Comparison simulation ↔ measurements:** although value for absolute minimum emittance agrees very well, **dependencies on operation parameters** (e.g. energy gain in booster) are very different. → studies have to be continued.
- **Laser system:** up to now rise/fall time of **6-8 ps** was possible → one of the reasons why **tails** in distributions dominate emittance number. This autumn, a **new laser system** will be installed which should allow **2 ps** rise/fall time. **Stability and usability** of the new system has to be observed during real operation.

- **RF system (I_{rf} and total power):**
 - up to now **only feed-forward** is possible (no regulation) → instabilities.
 - currently, 60 MV/m only reached with **saturated klystron** → no hat-space for regulation.
 - Several approaches ongoing to allow I_{rf} regulation and higher total power at the gun. (klystron with > 10 MW ???)
- **„Core emittance“:** to measure / optimize it → particles in **tails of PHASE SPACE** distributions have to be cut (not in coordinate space). This measurements require **very long & stable measurement time** → can only be done for **individual cases** at the moment. **Next year** we plan to install a tomography module which allows **phase space tomography** as standard measurement operation.
- **Slice emittance:** what finally counts is slice emittance in high current part of electron bunch. According to our current knowledge, the only way to **measure it with the required accuracy** is the usage of an **RF deflector**. E.g. also LCLS is intensively using their RFD to characterize their injector. Therefore, the development of the **RFD for PITZ** (e.g. pre-test of XFEL version) **should be continued**.

- **Optimize injector for XFEL baseline parameters:**

Ingredients:

- laser upgrade this year
- the installation of the CDS booster next year
- extension of the diagnostics beamline now and in next year(s)

→ we will be able to study the **evolution of the emittance for the full XFEL baseline parameters:**

- do experimental optimization
(full variation of experimental parameters,
systematic cathode studies, ..., 1-2 years)
- in parallel also requires further development of the simulations.

- Gun3.1 characterized at **~40 MV/m**:
 - operated with up to 3.5MW, **900 μ s RF**, 10Hz
 - $\epsilon_{x,n} = 1.32 \pm 0.11$ mm mrad
 $\epsilon_{y,n} = 1.43 \pm 0.17$ mm mrad **@1nC, (100% RMS)**
- Gun3.2 characterized at **~60 MV/m**:
 - operated with up to **6.7MW**, 140 μ s RF, 10Hz
 - $\epsilon_{x,n} = 1.25 \pm 0.19$ mm mrad
 $\epsilon_{y,n} = 1.27 \pm 0.18$ mm mrad **@1nC, (100% RMS)**
 - for 95%-RMS: $\epsilon_{x,y,n} \approx 0.8$ mm mrad !!
 - first demonstration of emittance required for European XFEL
 - thermal emittance: **$E_{kin} \approx 1.4$ eV**
 - $\epsilon_{th} = 0.47$ mm mrad (~50%)
- observed change of **chemical composition of Cs₂Te** cathodes using XPS
- upgrades at PITZ are ongoing → e.g. **new laser in 2007**